Investigations of Reverse Linking in Thin Bituminous Coal Seams

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Introduction

This research project is being conducted as an investigation into the feasibility of underground (in-situ) coal gasification in the Warrior Coalfield of Alabama. It is sponsored by the National Science Foundation and is being carried out by the Mechanical, Chemical, and Mineral Engineering Programs of The University of Alabama in cooperation with the Geological Survey of Alabama. The Warrior Coalfield is the largest and most productive of the coalfields of the state. In addition to the seams that are now being stripped or deep mined, there are numerous thin seams less than 100 cm. in thickness which cannot economically be recovered by conventional technology. At present, the deepest underground mine in Alabama is 610 meters but recent deep disposal well drilling shows coal at 1370 meters. This suggests the presence of additional coal seams between these depths that cannot be economically mined but may have potential for production by in-situ gasification.

Laboratory Investigations

Several problems present themselves when one attempts to gasify thin seams of bituminous coal in-situ that are not evident for thick seams of lower rank coals. Eastern bituminous coals are largely swelling coals, a property which causes linking paths to swell short closing off air passages which are necessary for continuation of the gasification process. Further, it is suspected that heat losses to surrounding strata may cause serious problems in the economical gasification of thin seams. For these reasons it was decided that extensive laboratory and analysis work would be necessary before any field combustion tests would be feasible.

Laboratory tests to date have been conducted in a combustor shown in Figure 1. This combustor is designed to allow both forward and reverse combustion and the results of any particular run can be examined without disturbing the combustion residue. Instrumentation ports are available for thermocouple and gas sampling probes.

Early runs on solid blocks of coal were carried out with a single central crack being provided for linkage between inlet and outlet. Since it is expected that actual linking in the field will be done by hydraulic fracturing, resulting in narrow vertical cracks, such a model for the laboratory combustor seems reasonable. Forward combustion runs in the combustor verified that crack closure occurs due to coal swelling and, in addition, to tar condensation in the crack. Reverse combustion, on the other hand, proceeds quite satisfactorily and a typical result of reverse combustion is shown in Figure 2. Due to the physical properties of the eastern bituminous coal it seems that additional linking by reverse burning will be

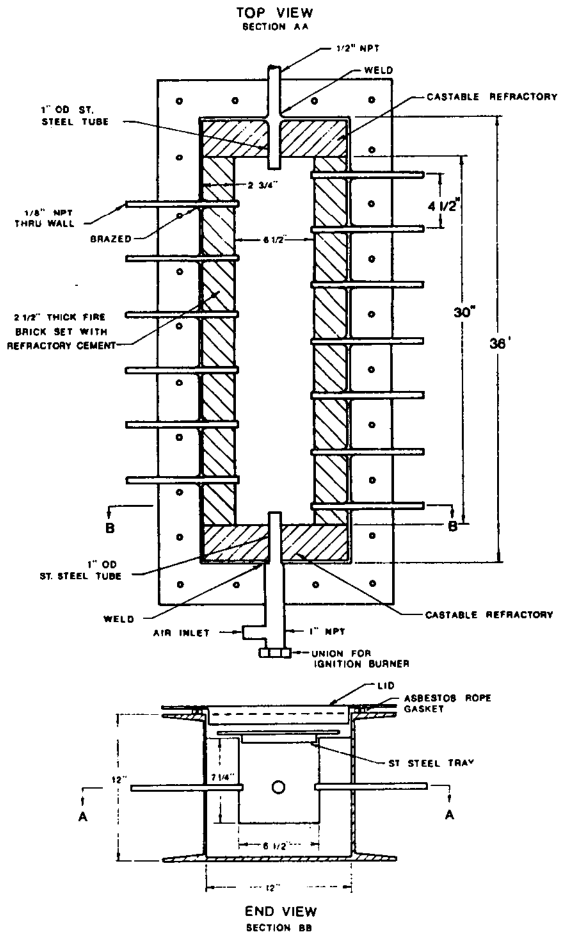


FIGURE 1

LABORATORY COMBUSTOR DETAILS

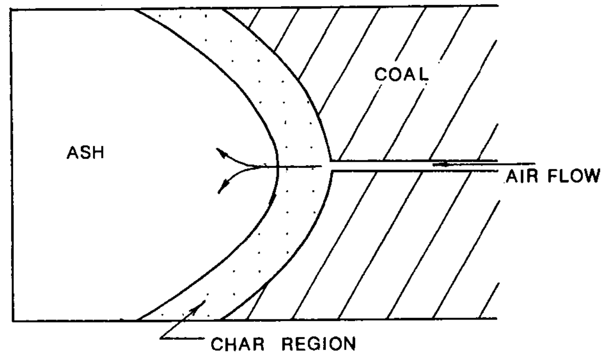


FIGURE 2

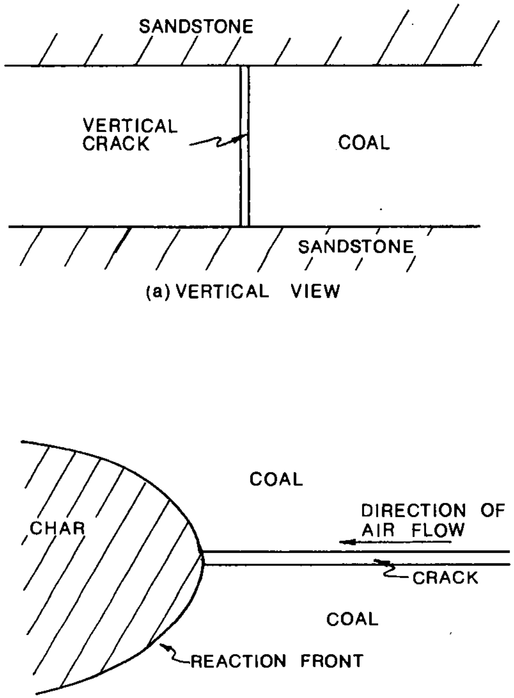
CONFIGURATION OF REVERSE BURN

necessary before a forward gasification process can take place. Primary concern is, therefore, presently being put on reverse linking procedures.

Early reverse combustion runs in the laboratory were made with high air flow rates and produced results similar to those shown in Figure 2. The burned-out region behind the thin carbonized zone is probably due to excess oxygen reacting with the carbon resulting in complete combustion. Since the objective of the linking process is to produce a carbonized zone which can then be gasified in the forward mode, it is important that the proper air flow be provided as that complete combustion is avoided. Further, the feasibility of the process will depend to a large extent on the radial extent of the carbonized zone and, since thin seams are being considered, heat losses to the surrounding strata will be important.

The approach to analyzing the reverse linking process will be two-fold. First, experiments in the laboratory combustor are currently being conducted to determine the relation between crack size, air flow rate and the extent of carbonization. During these experiments, measurements of temperature profiles within the coal are being made to provide estimates of temperature gradients. Past experiments have shown the gradients to be very steep so that coal within a few centimeters of the combustion zone shows little or no temperature rise. Secondly, a two-dimensional finite element heat conduction model is being adapted for use with the laboratory combustor. This program, written by Rohm and Haas Company for use with solid propellant rocket motors, can be used for thermally anisotropic, non-homogeneous bodies of complex geometry. The method of application will be to apply the model of Figure 3. Although the two-dimensional model will not strictly describe the three-dimensional case, it should provide some insight into the advance of the combustion zone. For example, when the program is applied to the model of Figure 3(a) it predicts isotherms as shown in Figure 4. Plans are to proceed stepwise into the coal moving the flame front and changing the boundary conditions as indicated by pyrolysis and air-flow experiments. The reasoning is that a portion of the heat that is produced by combustion is conducted into the coal seam raising its temperature thus pyrolyzing the coal at some distance ahead of the flame front. Further combustion occurs as a reaction between the pyrolysis products and air which has passed through the char to the reaction zone.

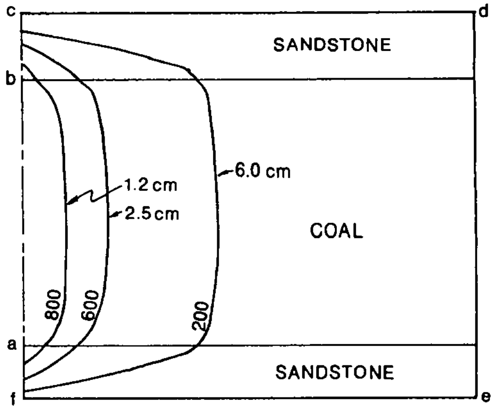
Laboratory pyrolysis experiments are presently being conducted to determine the rates at which various products are generated at different temperatures. The results of these pyrolysis experiments will be reported in a separate paper. The method of analysis will be to attempt to couple the combustion of the pyrolysis products and the resulting heat release with the conduction of heat into the coal and the consequent further pyrolysis. The finite element model allows a spatially variable boundary condition which will aid in this type of analysis. Actually, either of three boundary conditions may be used at the combustion front. These are constant temperature boundary, convection boundary, and constant heat flux boundary. Which of the three is to be used will depend on data obtained from this combustor and experience with the program. Since the oxygen supply will be greatest at the junction of the crack and the flame front, it is expected that this will be the region of greatest reaction and therefore the zone of fastest advance of the front. Thus, the hypothesis is that the carbonized zone will elongate as the pyrolysis reactions proceed and the question of interest becomes one of predicting the radial extent of the zone. Of course, multiple cracks will be present in the field case



(a) VERTICAL VIEW

(b) PLANE VIEW

FIGURE .3
TWO DIMENSIONAL MODELS FOR APPLICATION OF THE FINITE ELEMENT HEAT CONDUCTION PROGRAM



INITIAL CONDITIONS: 25° C

BOUNDARY CONDITIONS:

a-b: 1000° C
b-c: ADIABATIC
c-d: 25° C
d-e: 25° C
e-f: 25° C
f-a: ADIABATIC

COAL, $k = 2.16 \frac{cal}{hr\text{-}cm\text{-}°C}$

SANDSTONE, $k = 14.88 \frac{cal}{hr\text{-}cm\text{-}°C}$

FIGURE 4
RESULTS OF TWO DIMENSIONAL FINITE ELEMENT HEAT CONDUCTION PROGRAM AFTER ONE HOUR

but single cracks are considered here for analysis purposes. This method of analysis is expected to yield information on both rate and extent of the carbonization process as well as heat losses to the surrounding strata. The economics as well as as technical feasibility of the ultimate gasification process will depend in large part on the reverse linking process and our ability to predict its path and extent.